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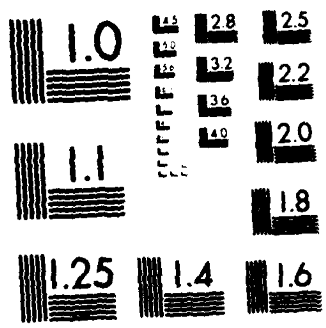

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HIERARCHICAL APPROACHES TO SOLUTION OF MODES

by

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1 Introduction

PDRC Report 86-09 discussed an averaging algorithm to solve the aggregate-disaggregate reformulation of MRMATE. The procedure was presented as an alternative to Benders' decomposition for solving the LIFTCAP/MRMATE linking problems in MODES in PDRC Report 87-06. This report presents two approaches for solving MODES.

The first approach formulates MODES as a hierarchy of decisions to be generated. The hierarchy consists of an aggregated version of LIFTCAP that generates allocation of assets to aggregate channels. An aggregate MRMATE model allocates MRs to these aggregated channels generated by aggregate LIFTCAP. An aggregate LIFTCAP model and an aggregate MRMATE model constitute the aggregate MODES model.

A solution to the aggregate MODES model is then disaggregated by disaggregate LIFTCAP and disaggregate MRMATE model. The disaggregate problems generate solutions at the required level of detail consistent with aggregate MODES solutions. Consistency implies that detailed channel capabilities and MR allocations added across an aggregate bundle is bounded by the aggregate channel capabilities and MR allocations generated by the aggregate MODES model.

The second approach considers the MODES problem from a different perspective. In some situations, the dominant objective is to move all MRs to their destination within their desired time window using the minimum number of assets. The driving problem in this version of modes is the MRMATE problem. MRMATE generates allocations of MRs to their best (minimum penalty) channels. This defines channel capabilities.

Given channel capabilities, the corresponding assets are required to realize these channel capabilities. This yields a model MINASSET which solves the problem of generating the minimum number of assets required. MINASSET also generates a cost of using a channel for the MRs. Interaction between MRMATE and MINASSET determines an allocation of MRs to channels that minimizes assets required to affect the delivery pattern provided as input to the MODES model.

2 A Hierarchical approach to MODES

A desirable feature of a hierarchical version of MODES is separation of the decision making process. The effect is that solutions generated by the procedure are consistent with desirable aggregate MODES solutions. Since the aggregate MODES model is of a smaller size, many iterations of aggregate MODES would be run until acceptable aggregate decisions are generated, then these decisions would be disaggregated to generate a MODES solution. Furthermore, aggregate solutions enable decomposition of the disaggregation process by region. This allows regional problems to be solved separately.

2.1 Aggregation of ports

The source region of POEs and the destination region of PODs are divided into regions. All channels between a pair of source- destination regions have the same cycle time. This implies that assets operating between POE-POD pairs in a pair of regions have the same travel time.

The aggregate LIFTCAP model consists of a network flow problem for channels between aggregate PODs and POEs and asset side constraints which limit total asset allocation across aggregate channels. Given an aggregate LIFTCAP solution, the disaggregate problems create one disaggregate LIFTCAP problem for each aggregate POE-POD asset triple.

LIFTCAP POEs are divided into L sets $P_1, \ldots, P_L$ and PODs are divided into M sets $S_1, \ldots, S_M$. The aggregate LIFTCAP model is:

$$\begin{aligned}
\textstyle\sum_a \sum_j s_{ija} &\leq \textstyle\sum_{k \epsilon P_i} C_k \; for \; i &= 1, 2, \ldots L \\
\textstyle\sum_a \sum_i s_{ija} &\leq \textstyle\sum_{k \epsilon S_j} D_k \; for \; j &= 1, 2, \ldots M \\
\textstyle\sum_i \sum_j w_{ija} \, s_{ija} &\leq A_a \; for \; a &= 1, 2, \ldots B \\
s_{ija} &\geq 0 &
\end{aligned}$$

Given an aggregate LIFTCAP solution, the disaggregate LIFTCAP problems are created as follows. For each of the $LxMxB$ sets of aggregated channels, the disaggregation problem $P_i - S_j - a$ generates detailed channel capabilities. Disaggregation problem $P_i - S_j - a$ is:

$$\sum k \in S_j \; c_{1ka} \leq C_i \; for \; 1 \in P_i$$
$$\sum_{k \in P_i} c_{kma} \leq D_j \; for \; m \in S_j$$
$$\sum_1 \sum_m c_{1ma} \leq s_{ija}$$

The aggregate and disaggregate LIFTCAP models have the matrix structure in Figure 1.

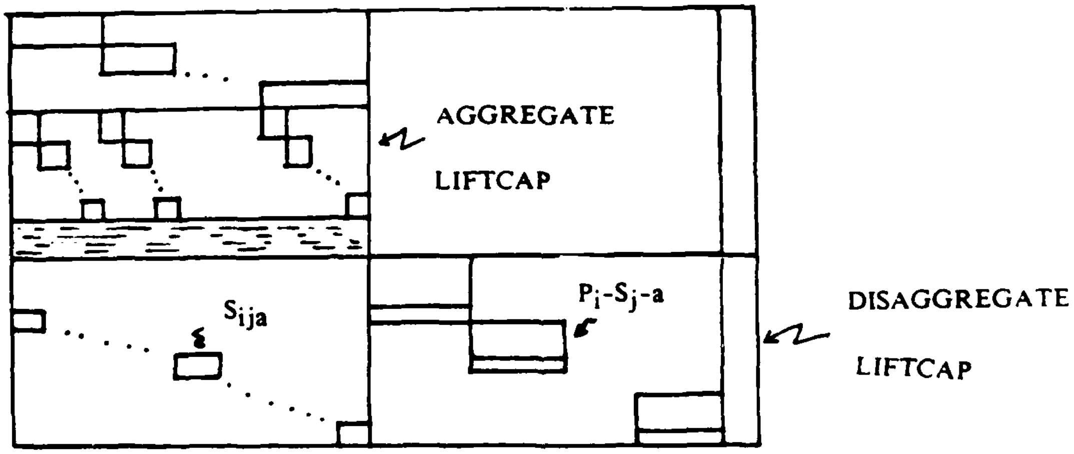

Figure 1: Aggregate and Disaggregate LIFTCAP structure

2.2 MRMATE Aggregation

PDRC Report 86-04 discussed different functional aggregation strategies for solution of MRMATE. The objective here is to create an aggregate MRMATE model that allocates MRs to aggregate channels. The aggregate channel capabilities are disaggregated by disaggregation problems which generate detailed MR allocations to detailed channels.

Channels are aggregated into sets of $LxMxB$ aggregate channels with capabilities provided by aggregate LIFTCAP (i.e. s_{ija}). Thus the aggregate MRMATE problem is expressed as

$$\begin{aligned} \textstyle\sum_{k \epsilon F(i,j,a)} yrk \; &= M_r \; for \; r = 1,2,\ldots T \\ \textstyle\sum_r y_{rk} \; &\leq s_{ija} \; for \; k = 1,2,\ldots (LxMxB) \\ y_{rk} \; &\geq 0 \end{aligned}$$

MRMATE Disaggregation problems assign MRs to detailed channels. This results in a disaggregation problem for each set of aggregated channels, yielding in $LxMxB$ disaggregation problems.

Disaggregation problem ija becomes

$$\begin{aligned} &\min \textstyle\sum_l \sum_m p_{lm} \, x_{lm} \\ s.t. \; \textstyle\sum \; m \; \epsilon \; F(i,j,a) \; xlm \; &= ylk \; for \; 1 = 1,2,\ldots T \\ \textstyle\sum_l x_{lm} \; &= c_k \; for \; k \; \epsilon \; F(i,j,a) \\ x_{lm} \; &\geq 0 \end{aligned}$$

The aggregate and disaggregate MRMATE models have the structure in Figure 2.

2.3 Aggregated LIFTCAP and MRMATE Models

Consider the aggregate LIFTCAP and MRMATE models in conjunction. It has the structure in Figure 3. The aggregate LIFTCAP model generates channel capabilities required at the level of the aggregate MRMATE model. Rearranging the blocks in Figure 3 a structure as in Figure 4 is produced.

Figure 4 presents a hierarchical model of MODES. Aggregate LIFTCAP and aggregate MRMATE models represent the aggregate MODES models. The aggregate MODES model generates aggregate channel capabilities and an allocation of MRs to aggregate channels. Aggregate channels represent an allocation of MRs to regions, i.e. POE-POD regions. The aggregate MODES model has the same structure as the MODES model but is of a much smaller size.

Smaller size of the aggregate MODES model implies that various asset allocation scenarios can be analyzed to determine a suitable aggregate asset allocation very quickly.

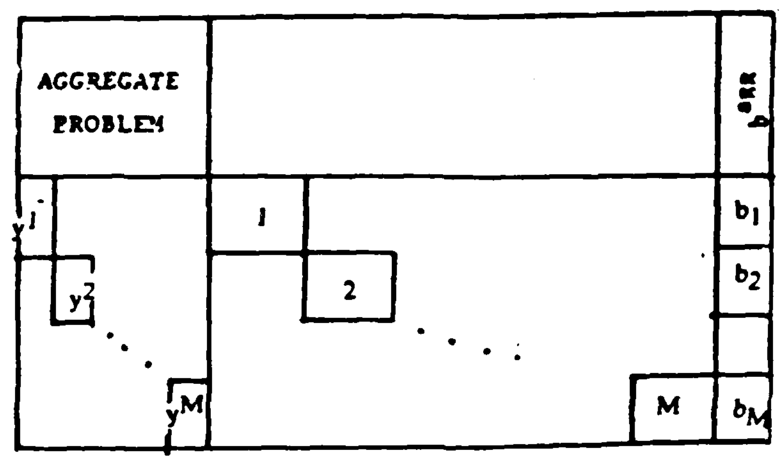

Figure 2: Aggregate - Disaggregate MRMATE Models

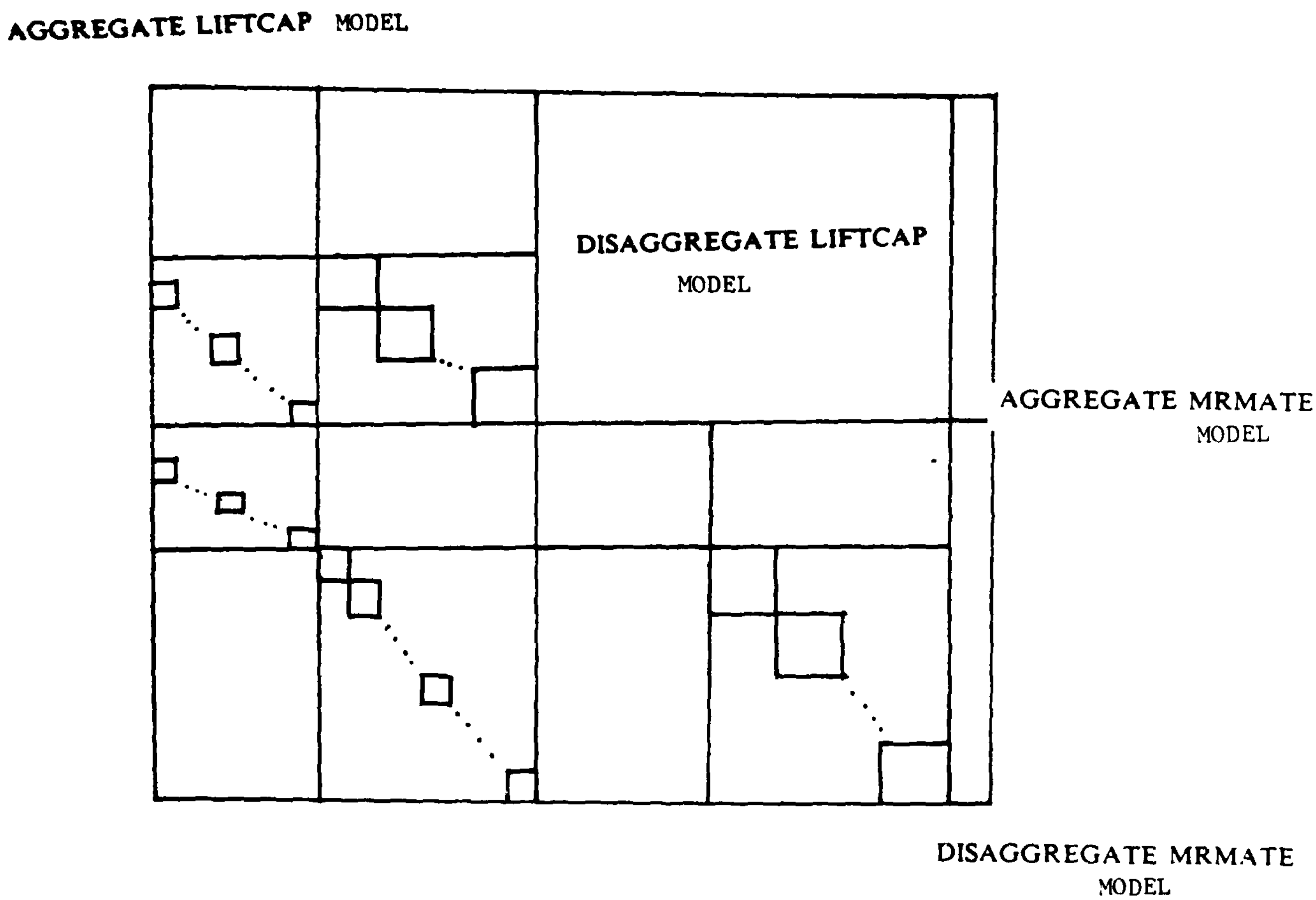

Figure 3: Combined MRMATE and LIFTCAP structures

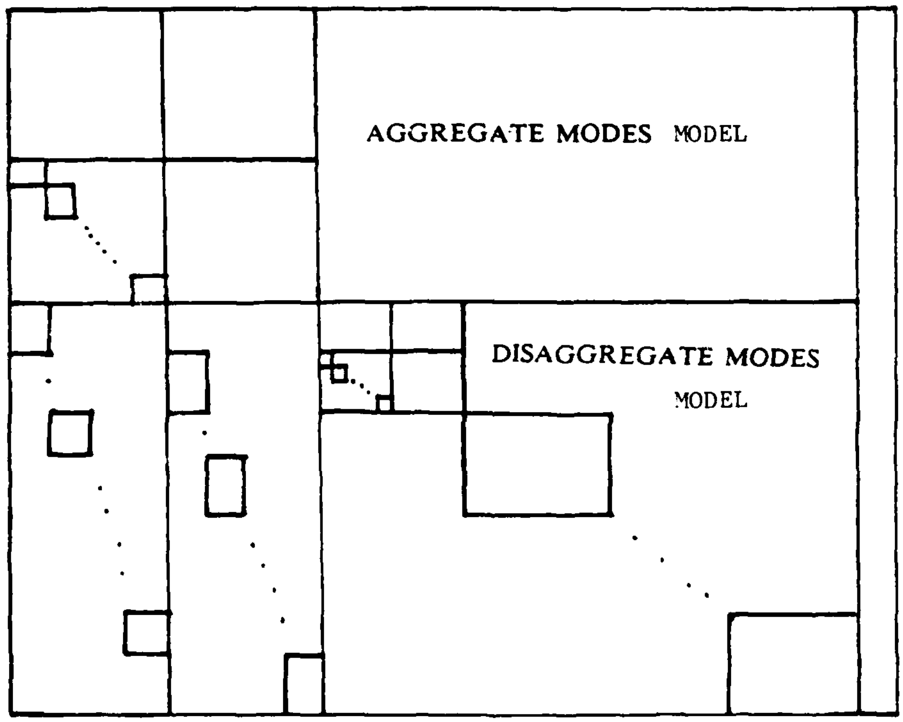

Figure 4: Hierarchical MODES Model

The disaggregate MODES model attempts to generate asset allocations and channel capabilities consistent with the aggregate solution. This implies that each POE-POD region can be treated independently in the disaggregate MODES model to generate MR allocations at each regional level consistent with aggregate asset allocations and MR assignments.

The disaggregate MODES model generates detailed channel capabilities consistent with aggregate asset allocations and detailed MR allocations to these channels. Given an aggregate solution, from in Figure 4 it can be seen that the disaggregate problems separate into $LxMxB$ disaggregate problems, one for each POE-POD region and asset type. The structure of the MODES disaggregate problems, for a given aggregate solution, is the same as the MODES structure itself.

The disaggregate problems are again of much smaller size than the original MODES model. Furthermore, the disaggregate problems are restricted to each POD-POE region and asset type. This implies that the disaggregate problems can also be used to generate detailed problem information in terms of port capacity and channel capability.

2.4 A solution procedure using averaging

The problem structure in Figure 4 could be exploited the aggregate and disaggregate MODES problems could be decomposed in such a manner as to maintain structure at each iteration of an iterative solution process. PDRC Report 86-09 discusses use of an averaging procedure to solve re-formulated aggregate disaggregate MRMATE. The algorithm is asymptotically optimal and provides the desirable features outlined above.

The algorithm would work as follows:

1. Initialize the solution process by generating an aggregate MODES solution that is disaggregated to generate duals for the disaggregation problems.

2. Use the disaggregate problem duals, associated with each of the aggregate channels and aggregate POE-POD arcs, to generate an aggregate MODES solution optimal with respect to these costs. (The aggregate problem objective function value generates a lower bound to the overall MODES problem.)

3. Average the aggregate solutions generated up to and including this iteration and disaggregate the averaged aggregate solution generated.
4. The aggregate solution, when disaggregated, generates disaggregate duals which are again averaged across all disaggregate duals generated through this iteration. (The disaggregate problems generate an upper bound to the overall MODES problem.)
5. Repeat steps 2 through 4 until the upper and lower bounds differ by less than some prespecified value.

3 An alternative approach to MODES

This approach, called ALLOCATE, considers relaxation of asset constraints and port capability constraints at each iteration of the model. Successive iterations improve asset and port capability feasibility of MR allocations generated. At every iteration, delivery patterns are generated which fall within specified time windows. If the assets available are less than required to affect the specified delivery pattern, then the procedure generates the minimum assets required to maintain this delivery pattern.

3.1 Allocation of MRs to channels

The master problem is the allocation of MRs to channels. This is a transportation problem with channel capabilities, i.e. supplies unspecified and costs depending on channel capability usage. The objective is to generate an allocation of MRs to channels, which specifies the channel capabilities, that minimizes MR to channel allocation penalties as well as generates the minimum cost channel allocation.

$$\begin{array}{c} \min \sum_i \sum_j p_{ij}\, x_{ij} \;+\; \sum_j c_j \\ s.t.\ \sum_j x_{ij} \;= m_i \ for\ i \;= 1,2,\ldots,M \\ \sum_i x_{ij} \;-\; c_j \;= 0\ for\ j = 1,2,\ldots,N \\ x_{ij} \;\geq 0 \end{array}$$

The optimal solution to this problem would result in each MR choosing a single channel. This is a desirable feature if MR split across channels is not desirable.

3.2 Determining Asset requirements

Given a set of channel capabilities generated by the master problem of ALLOCATE, the minimum number of assets required to realize that set of capabilities must be determined. This problem is called MINASSET. Furthermore, if a set of costs associated with each of the asset types along with capability constraints is given, the subproblem determines a minimum set of assets that realize the capabilities specified.

The minimal number of assets is determined by creating a minimum cost network flow model. Nodes in the model represent channels. An arc is included from node (channel) i to node (channel) j if an asset can complete the task of moving MRs along channel i and travel to the POE of channel j and get to its destination before the time specified by channel j.

Each asset type generates a different minimal cost network. Asset capacities provide the number of units of each asset required to realize channel capabilities.

3.3 Generating channel capability costs

When the subproblem is solved, a set of asset requirements is generated along with a dual variable for each of the nodes (channels). Duals associated with nodes reflect the cost of using that channel for any MR. These duals are used as costs on channels in the master problem of ALLOCATE. New costs are used to generate a revised MR allocation with respect to assets required and this completes an iteration.

3.4 A solution procedure using averaging

The solution procedure is based on the averaging approach described in PDRC Report 86-09. It has the property that problem structure is maintained for both the master and subproblems at each iteration. It converges asymptotically to the global optimal solution. The algorithm works as follows:

1. Solve MRMATE and generate MR allocations to channels. This determines a set of node capability constraints for the subproblem. Channel costs in the first iteration are set to some reasonable estimates.

2. For the channel capabilities generated, solve the subproblem to generate a minimal number of assets required, together with duals for all channels.

3. Solve the master problem with these duals as costs on channels and generate a new MR allocation. (This generates lower bounds to the overall problem.)

4. Average across all MR allocations generated thus far and use that average solution for the subproblem.

5. Solve the subproblem with this new MR allocation to generate channel duals. (This problem generates upper bounds on the objective function value.)

6. Average across all channel duals and use this information in the master problem. Stop if the difference between upper and lower bounds is less than some prespecified value.

4 Conclusions

The two approaches presented in this report present alternatives to the current implementation of MODES.

The hierarchical MODES model attempts to reduce problem size while maintaining structure. The strategy is to separate out MODES problems by POE-POD regions and enable independent analysis. It also enables various alternative asset allocation scenarios to be tested quickly at the aggregate level before analyzing the problem in detail. Finally, since the averaging procedure maintains problem structure at each iteration, efficient codes can be used to solve the problem at each iteration.

ALLOCATE represents an approach in which the emphasis is on generating delivery patterns at the cost of the availability constraints. Successive iterations generate delivery patterns which use a lesser number of assets. Stopping at any iteration would provide the desired delivery pattern but would use more assets than available. This model is suitable in situations wherein the number of assets must also to be determined as a parameter in the model. (Often, the asset constraint is not a hard constraint.) Thus

if the procedure is stopped at a solution wherein the assets required do not differ considerably from the number of assets available, then a satisfactory solution has been obtained.

The disadvantage of ALLOCATE, as described, is that it ignores port capability constraints. Procedures are required which would incorporate this information into the ALLOCATE model while maintaining exploitable structure. One alternative is to assume that port capability is specified by asset type. If so, then this information can be included in the form of a dummy node in LIFTCAP.

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